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CP Violation in Hadronic B Decays at CDF

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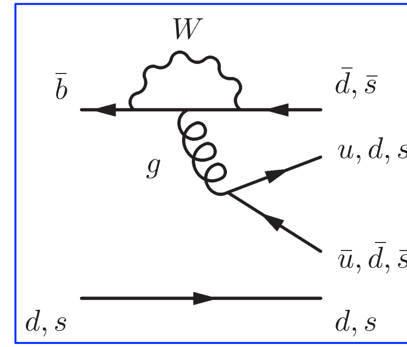
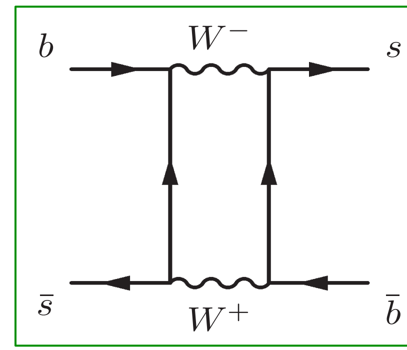
On behalf of the CDF Collaboration

Hadronic B Decays

Higher-order amplitudes (penguins, box) play significant role. Access to CKM phases from amplitudes' interferences (e.g. γ , β_s).



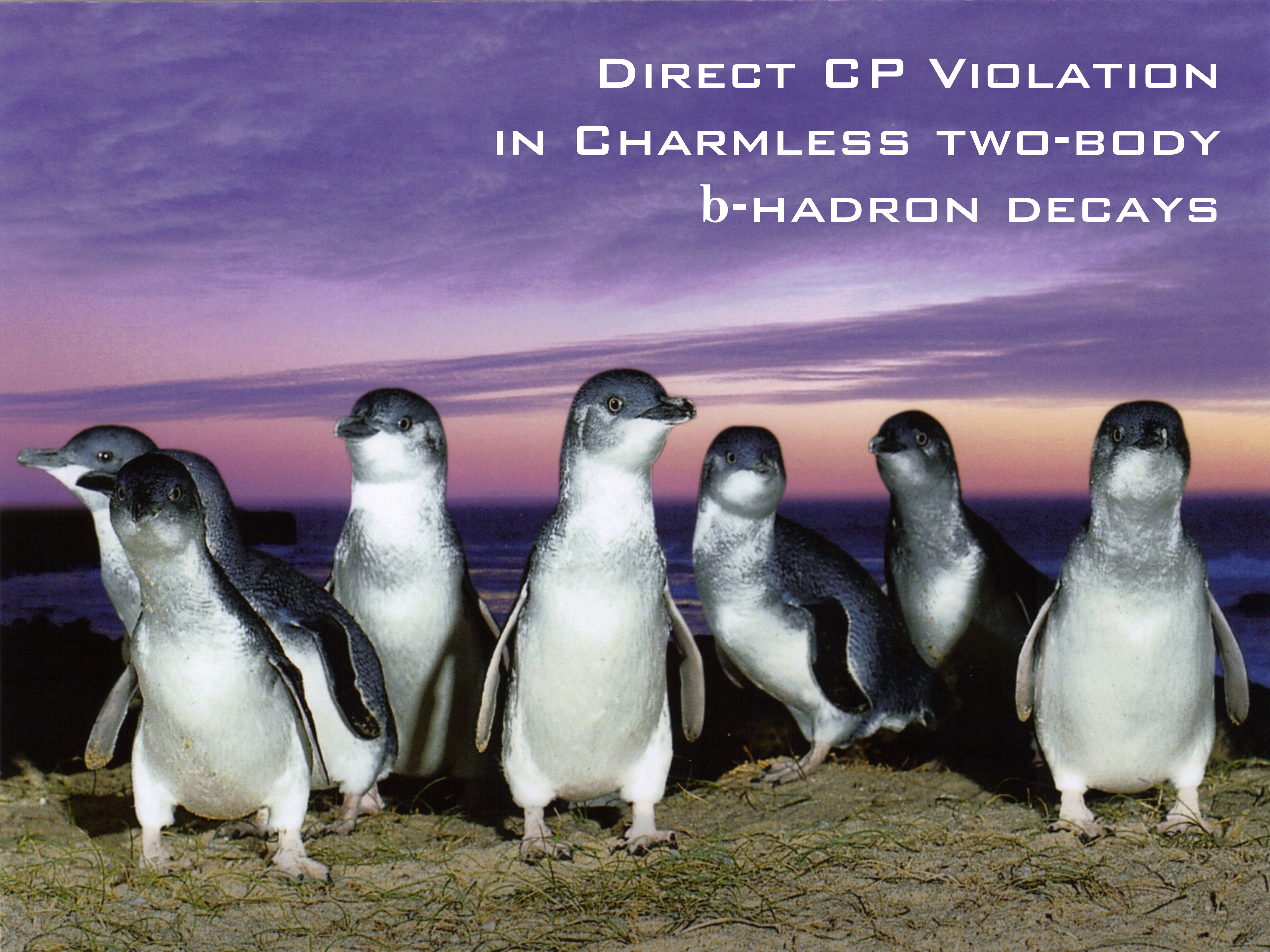
NP as new source of CP-violation: provide(enhance) new(strongly-suppressed) operators; introduce new weak phases.



Hard part: often disentangle NP from large hadronic uncertainties.

Today from CDF

- ❑ Direct CPV in $B_{(s)}^0 \rightarrow K^+\pi^-$ and $\Lambda_b^0 \rightarrow pK^-/\pi^-$ with full data set.
- ❑ B_s^0 mixing phase, τ_s and $\Delta\Gamma_s$, with full data set.
- ❑ BR of $B_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-}$ and of $B_s^0 \rightarrow J/\psi\, \phi$ with full data set

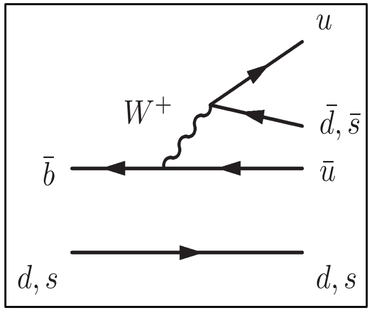

Direct CP Violation
in Charmless two-body
b-hadron decays

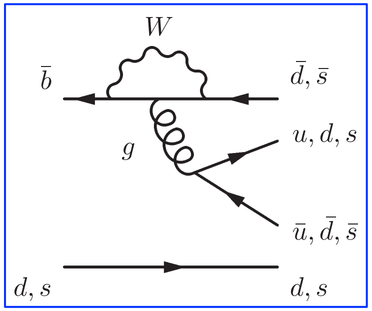
Direct CPV in Charmless b-hadron decays

$B^0 \to K^+\pi^-$, $\pi^+\pi^-$, K^+K^-

$B_s^0 \to K^-\pi^+$, $\pi^+\pi^-$, K^+K^-

$\Lambda_b^0 \to p\pi^-$, pK^-





Direct CP violation

$K\pi$ Puzzle from Belle. SM or NP?

Likely SM, large hadronic uncertainties.

Need experimental constraints from several decays.

B^0_s sector can shed light. $B_s^0 \to K^+\pi^-$ nearly model independent test;

Expect $A_{CP} \sim 30\%$-50%, consistent with first LHCb evidence:

$(27 \pm 8 \pm 2)\%$ - PRL 108 (2012).

Baryon decays provide additional information.

New for ICHEP:

direct CP asymmetries with full CDF Run II datset

Strategy

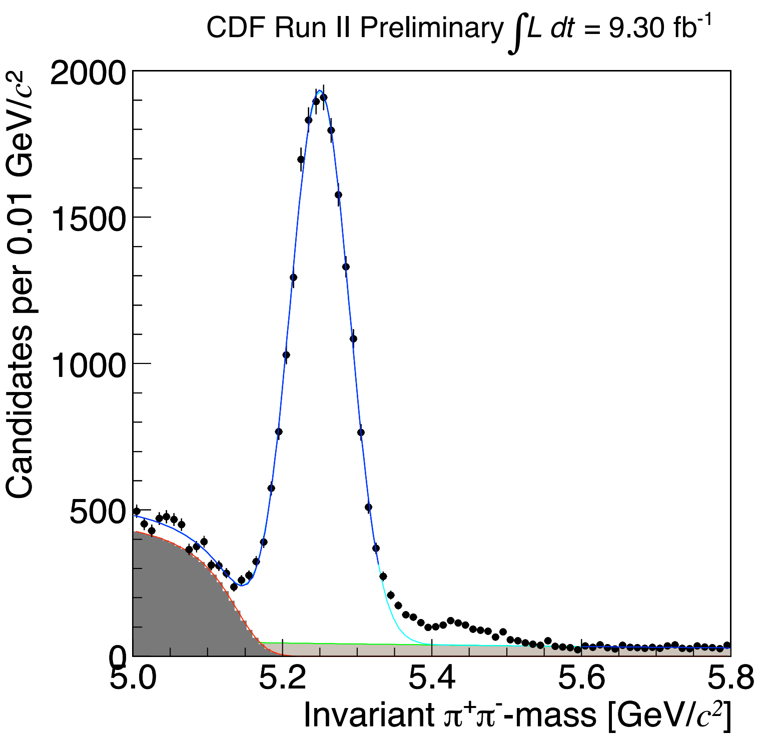
Equal b and $\bar{b}$ production.

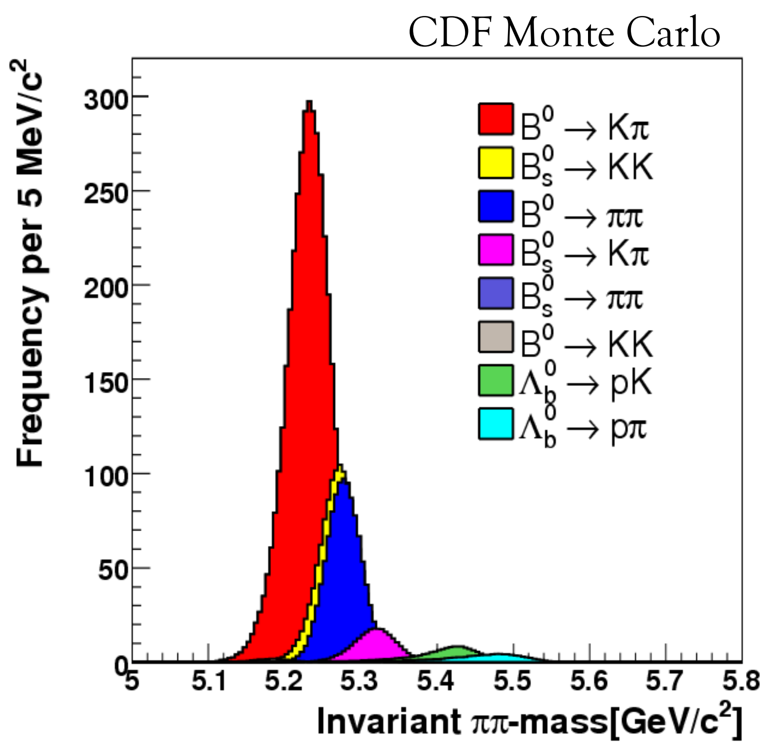
Flavor specific decays. b-flavor from final-state's charges.

"Count and correct" (for detector-induced charge asymmetries).

$$A_{CP} = \frac{N(b \to f) - c_f N(\bar{b} \to \bar{f})}{N(b \to f) + c_f N(\bar{b} \to \bar{f})}$$

Individual modes overlap in a single peak (width ~38 MeV/c^2).



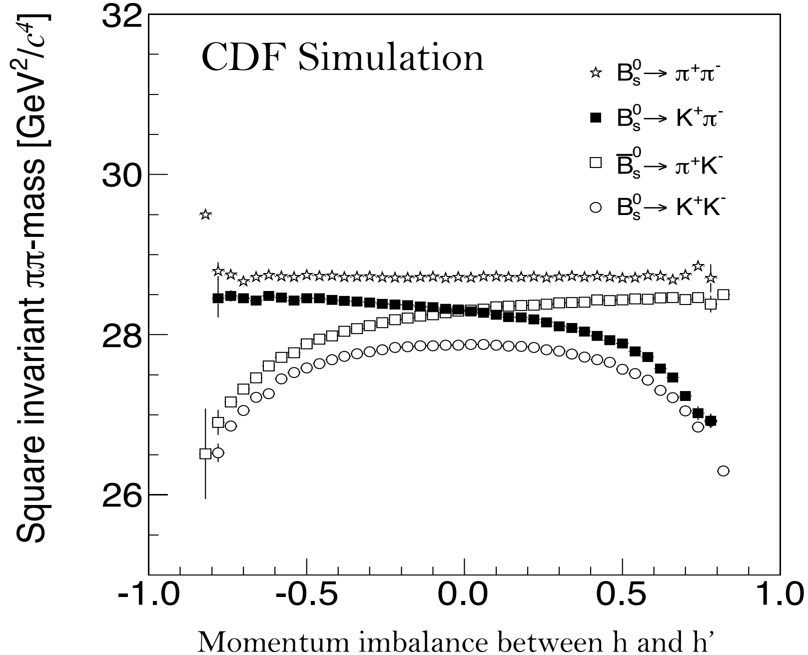


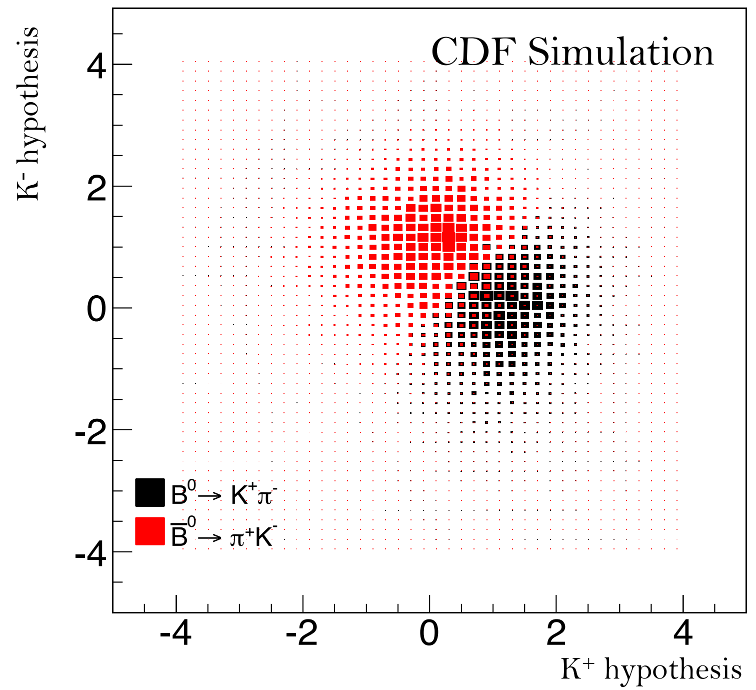
Sample Composition

Signal yield from a Likelihood fit. Ensure statistical separation-power combining information from kinematics (mass and momenta) and particle ID.

Data-driven approach

- 2.0 σ separation for $K^+\pi^-/\pi^+K^-$.
  Calibrate on large sample of $D^0 \to K^-\pi^+$ and $\Lambda^0 \to p\pi^-$.
- $\pi\pi$ mass resolution
  Checked on large samples of $D^0 \to K^-\pi^+$ and $D^0 \to \pi^-\pi^+$.
- Detector-induced asymmetry
  O(1-2%) measured on data with $D^0 \to K^-\pi^+$ and $\Lambda^0 \to p\pi^-$ decays





Results

$A_{CP}(B^0 \rightarrow K^+\pi^-) = (-8.3 \pm 1.3 \pm 0.3)\%$

$A_{CP}(B_s^0 \rightarrow K^-\pi^+) = (22 \pm 7 \pm 2)\%$

Competitive measurement for B^0.
For B_s^0 confirm LHCb result with same resolution.
Strong evidence ($4.5\,\sigma$) combining CDF and LHCb measurements:
$A_{CP}(B_s^0 \rightarrow K^+\pi^-) = (24.2 \pm 5.4)\%$

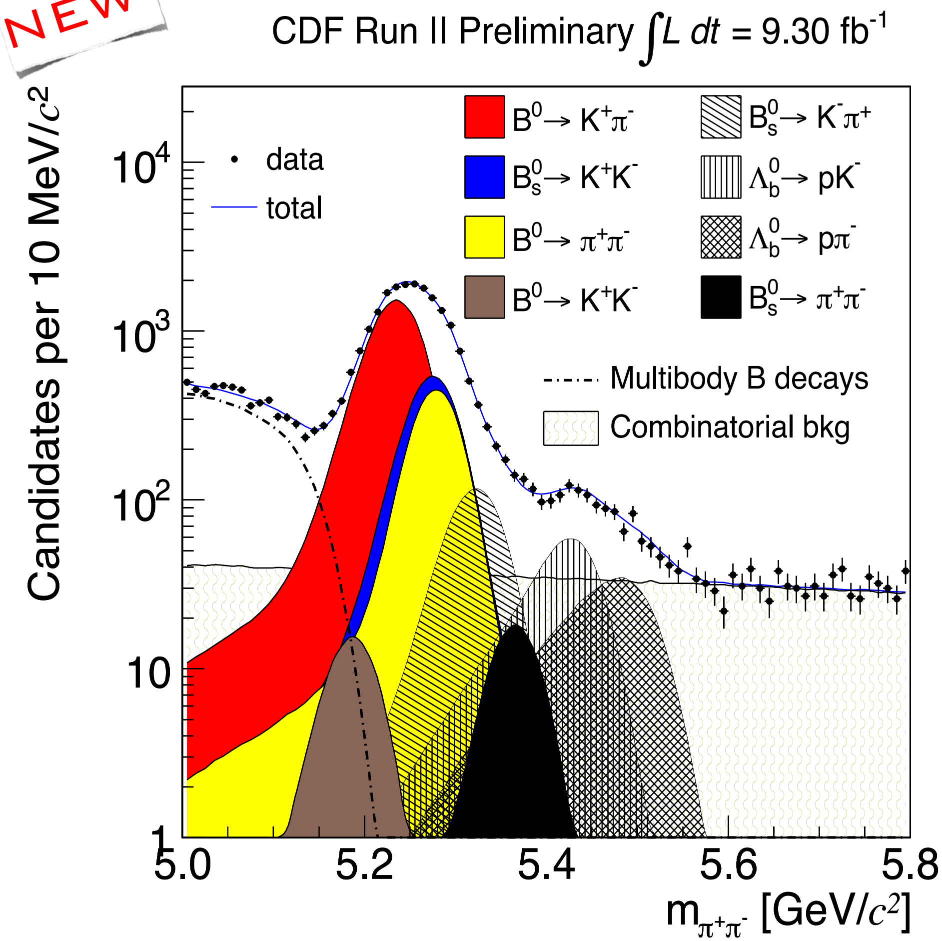
$A_{CP}(\Lambda_b^0 \rightarrow p\pi^-) = (7 \pm 7 \pm 3)\%$

$A_{CP}(\Lambda_b^0 \rightarrow pK^-) = (-9 \pm 8 \pm 4)\%$

Uncertainties halved w.r.t. the only last CDF measurement.
Large asymmetries disfavored.

[CDF Note 10726]

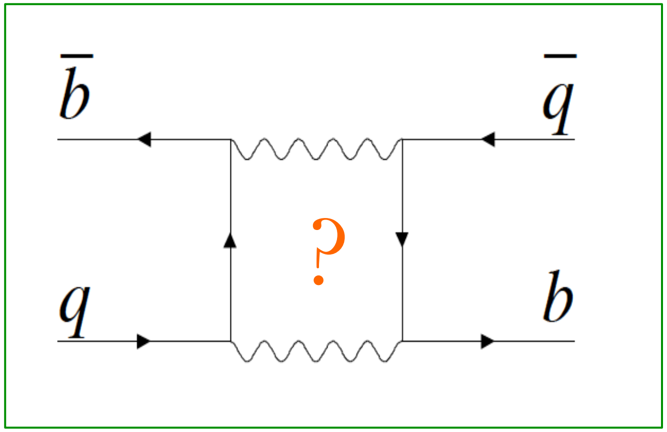
NEW



$N_{tot}(B^0 \rightarrow K^+\pi^-) \sim 11700$
$N_{tot}(B_s^0 \rightarrow K^-\pi^+) \sim 900$
$N_{tot}(\Lambda_b^0 \rightarrow p\pi^-) \sim 450$
$N_{tot}(\Lambda_b^0 \rightarrow pK^-) \sim 600$

CP Violation in B_s mixing

Search for NP in B_s Mixing



CP violation in B_s^0 mixing

Can be significantly altered by NP.

2011 DØ

$\sim 4\sigma$ deviation from SM in B semileptonic asymmetry.

Independent cross-check is crucial.

Constrain BSM physics in B_s^0

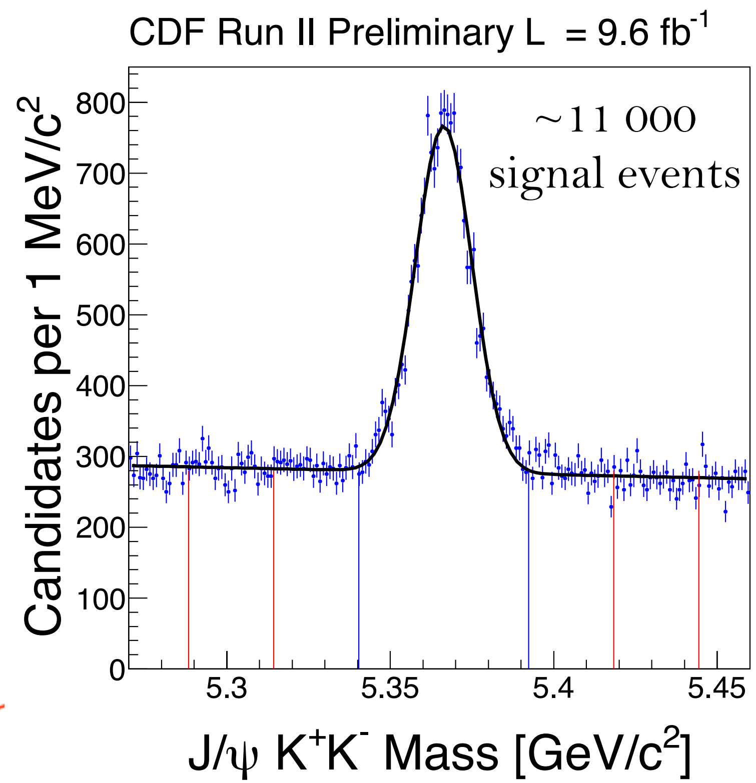
- ❑ CP-violating mixing phase β_s
  largely suppressed in SM
- ❑ $B_s^H - B_s^L$ decay difference $\Delta\Gamma_s$
  $\neq 0$ in SM

$B_s^0 \rightarrow J/\psi\ \phi$

Exploit interference between decays w/ and w/o flavor oscillations.

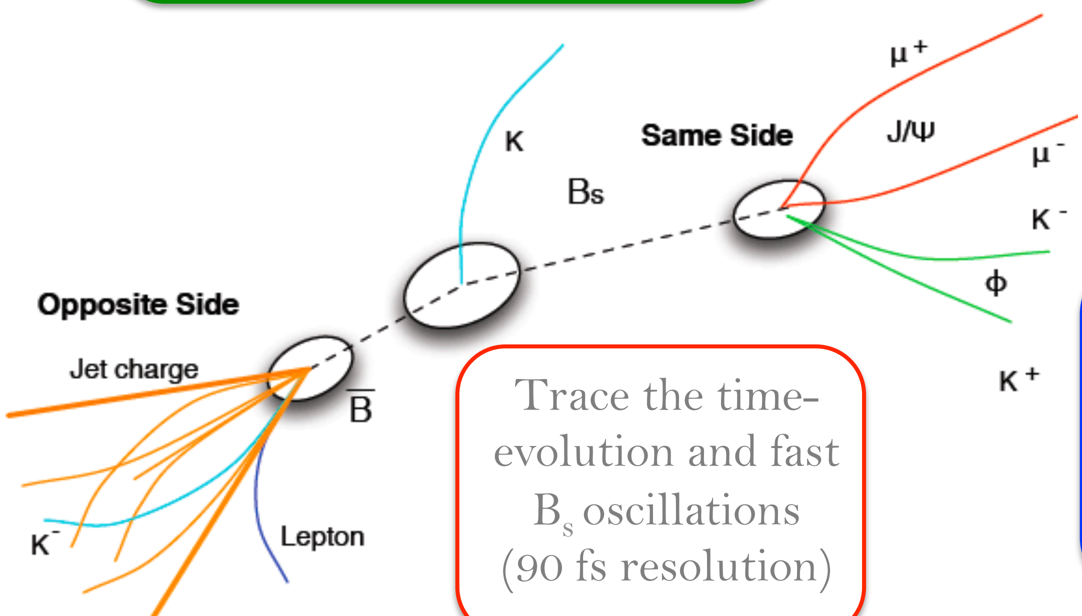
B_s mixing phase with $B_s^0 \to J/\psi\ \phi$

Joint fit to mass, production flavor, decay-time, decay-angles



Look at other B ($\varepsilon D^2 \sim 1.4\%$)

Look at K in fragmentation with B_s ($\varepsilon D^2 \sim 3\%$)



Trace the time-evolution and fast B_s oscillations (90 fs resolution)

Disentangle CP-even/CP-odd final state

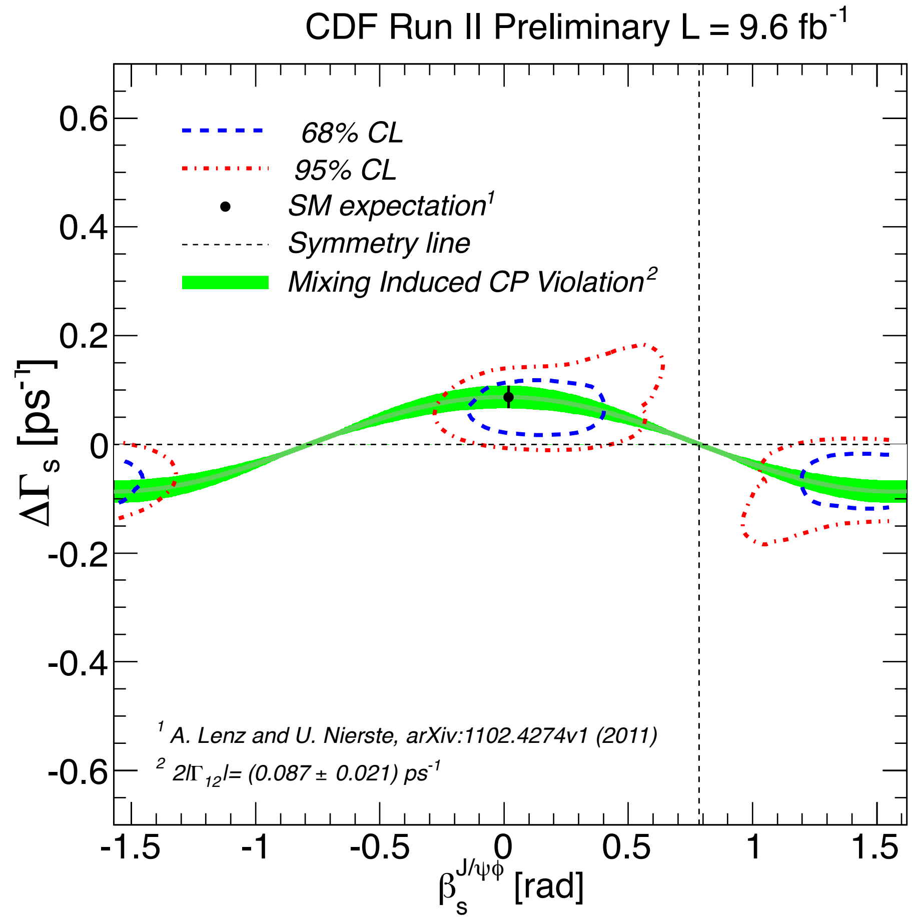
Include J/ψ KK S-wave contribution

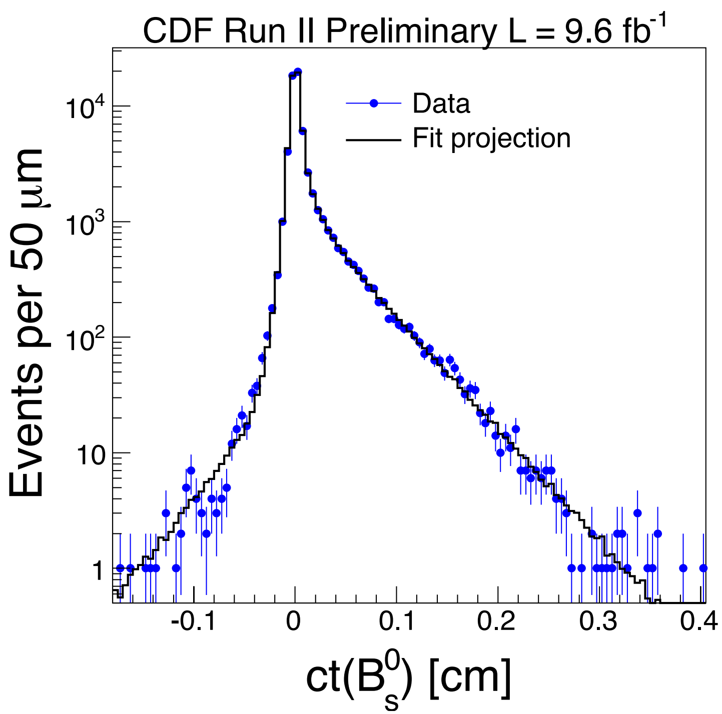
B_s mixing Results

Full dataset analyzed. Consistent with SM ($<1\sigma$) and other experiments.

β_s in [-0.06, 0.30] rad @ 68% C.L.

[CDF Note 10778]





Assuming SM CP-violation,

$$\Delta\Gamma_s = 0.068 \pm 0.026 \pm 0.007 \text{ ps}^{-1}$$

$$\tau_s = 1.528 \pm 0.019 \pm 0.009 \text{ ps}$$

Agreement and competitive with other experiments.

Updating the Reference

Current PDG BR($B_s^0 \rightarrow J/\psi\,\phi$) dominated by CDF Run I measurement (1996), ~30% uncertainty.

Update with full Run II statistic

Normalize to BR($B^0 \rightarrow J/\psi\,K^*$). Account for S-wave contributions (dominated syst. uncertainty).

$$\frac{f_s}{f_d}\frac{Br(B_s \to J/\psi\phi)}{Br(B^0 \to J/\psi K^*)} = 0.239 \pm 0.003(stat.) \pm 0.019(sys.)$$

NEW

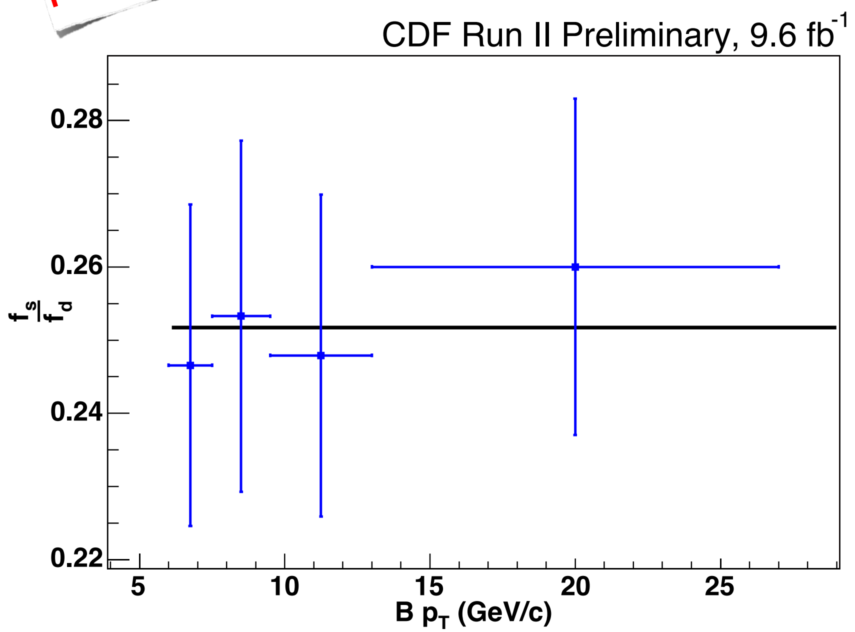
[CDF Note 10795]

Using recent Belle result, extract f_s/f_d and measure the dependence on p_T.

$$f_s/f_d = (25.4 \pm 0.3 \pm 2.0 \pm 4.4)\%$$

Or get the BR($B_s^0 \rightarrow J/\psi\,\phi$) using known f_s/f_d and BR($B^0 \rightarrow J/\psi\,K^*$)

$$BR = (1.18 \pm 0.02 \pm 0.09 \pm 0.15)\ 10^{-3}$$



From the CP-even side

$B_s^0 \to D_s^{(*)+} D_s^{(*)-}$

Predominantly CP-even. Can probe Γ_L.

Use 6.8 fb^{-1} collected by displaced track trigger to measure BR.

Simultaneous fit to signal $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$ and normalization mode $B^0 \to D_s^+ D^-$

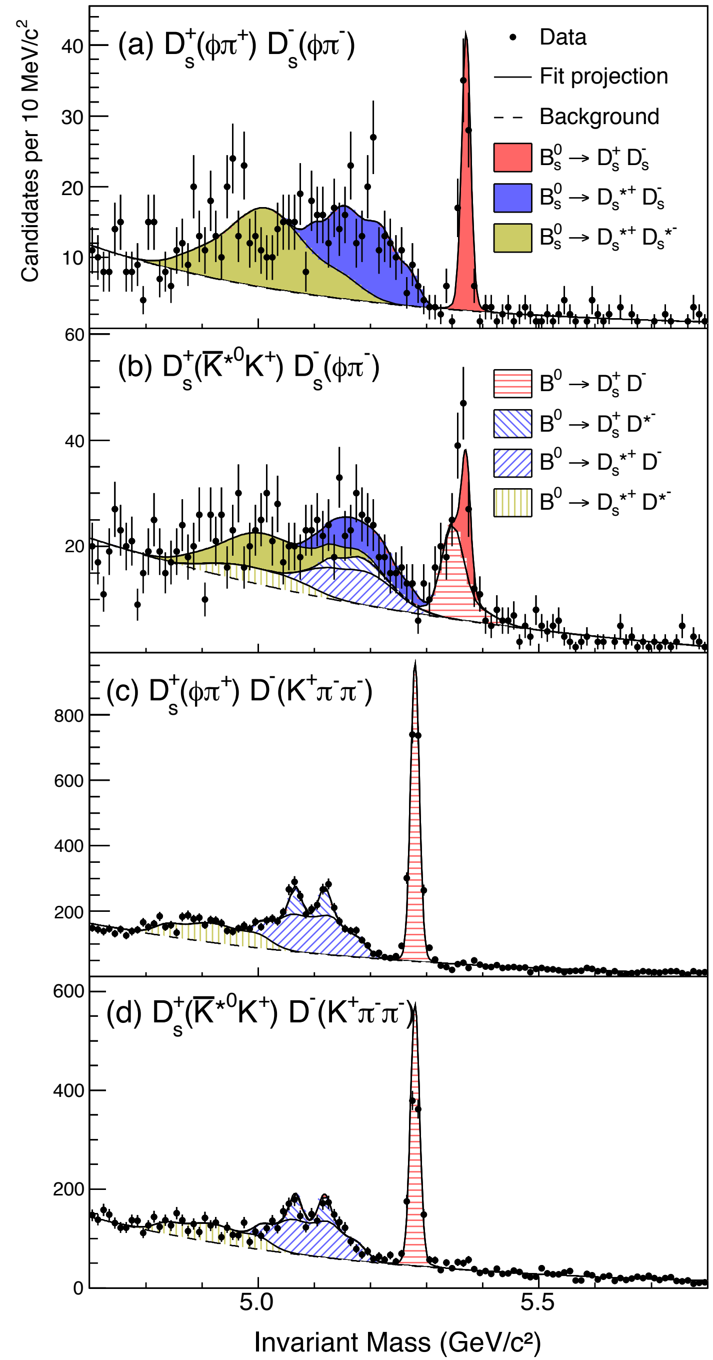
Full $D_s^+ \to K^+ K^- \pi^+$ Dalitz structure for precise determination of acceptance.

$BR(B_s \to D_s^+ D_s^-) = (0.49 \pm 0.06 \pm 0.05 \pm 0.08)$ %,

$BR(B_s \to D_s^{*\pm} D_s^{\mp}) = (1.13 \pm 0.12 \pm 0.09 \pm 0.19)$ %,

$BR(B_s \to D_s^{*+} D_s^{*-}) = (1.75 \pm 0.19 \pm 0.17 \pm 0.29)$ %,

$BR(B_s \to D_s^{(*)+} D_s^{(*)-}) = (3.38 \pm 0.25 \pm 0.30 \pm 0.56)$ %,



[PRL 108 (2012)](#)

Conclusions

Data taking ended in September 30th 2011.
Getting analyses finalized in full dataset.
Shown results are less than 6 months old.

CDF keeps contributing to HF
while passing baton to LHC experiments.

Confirm LHCb direct CPV in $B_s^0 \rightarrow K^+\pi^-$ with same resolution, providing strong evidence. Unique A_{CP} measurements in Λ_b^0 decays.

B_s^0 mixing phase closer to SM. Competitive measurements of τ_s, $\Delta\Gamma_s$

Precise BR measurements
($B_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-}$, $B_s^0 \rightarrow J/\psi\,\phi$)

Will focus on measurements that are unique to Tevatron or systematics-limited.
Still interesting results to come.

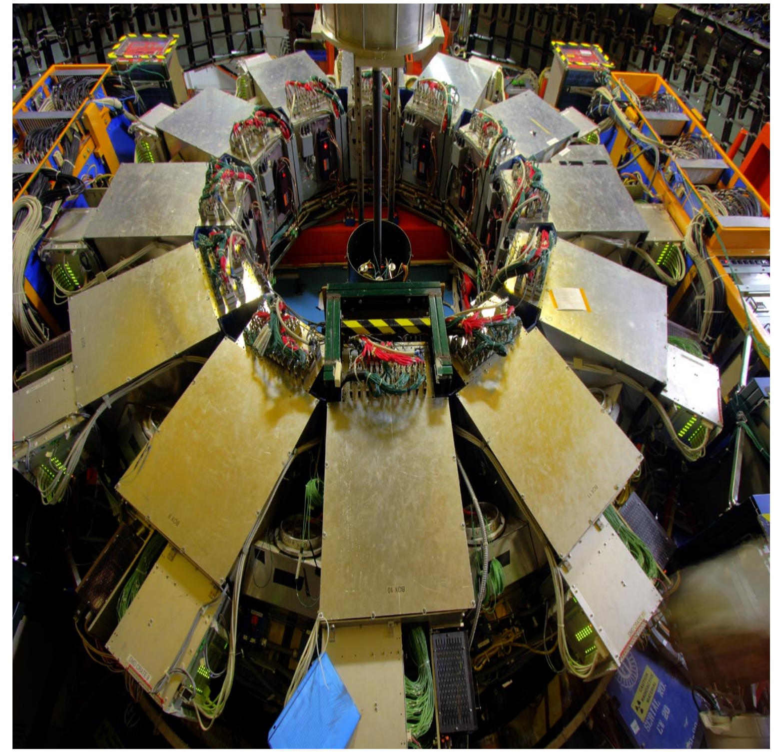
Backup

CDF

10 fb^{-1} of $p\bar{p}$ collisions @ 2 TeV on tape.
All species of heavy flavors.

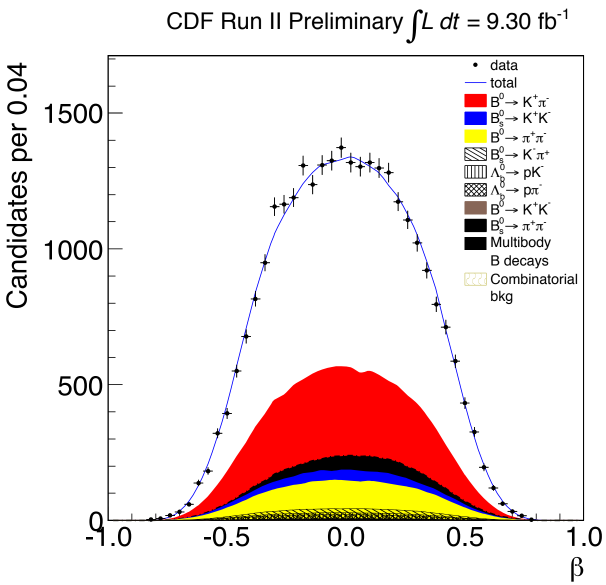
Good tracking, $\sigma(p_T)/p_T^2$=0.1%.
9 MeV of B mass resolution and 90 fs of decay-time resolution for $B_s^0 \to J/\psi\,\phi$ decays.

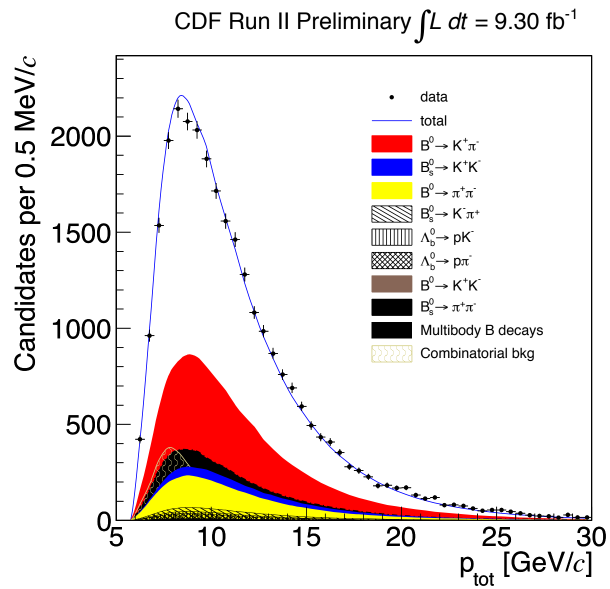
Powerful triggers
Silicon for tracks displaced from $p\bar{p}$ vertex (45 μm IP resolution).
Low-p_T muons for $J/\psi\,X$ final state (80% acceptance @ $|\eta|<1$)

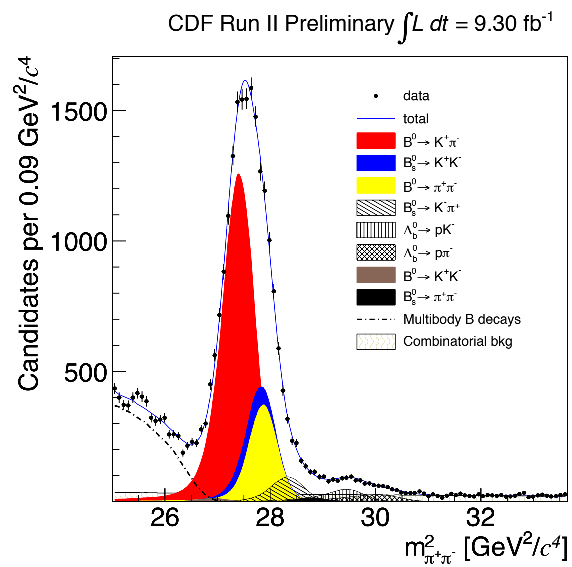


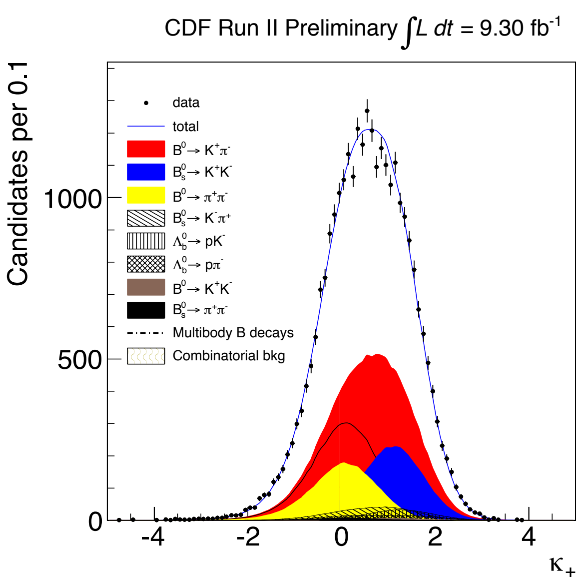
Shut down 30 Sept. 2011. Getting the analyses finalized in full dataset.

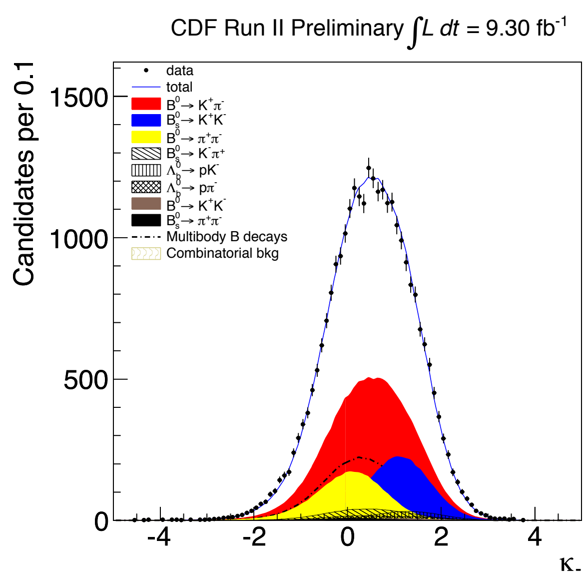
B → hh' Fit Projections







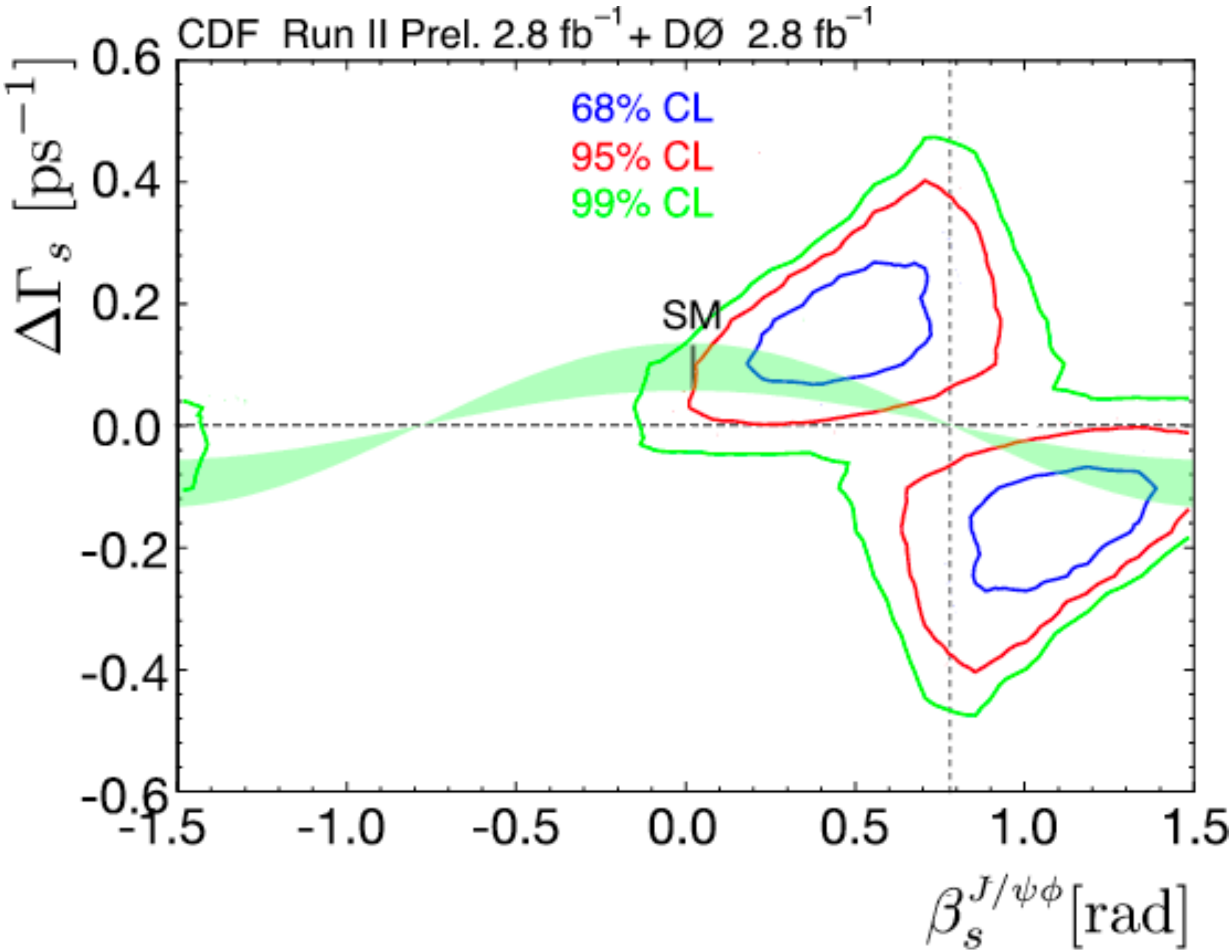




B → hh' Systematics

source	$A_{CP}(B^0 \to K^+\pi^-)$	$A_{CP}(B_s^0 \to K^-\pi^+)$	$A_{CP}(\Lambda_b^0 \to p\pi^-)$	$A_{CP}(\Lambda_b^0 \to pK^-)$
Charge asymm. of momentum p.d.f	0.0011	0.0025	0.0009	0.0022
Signals momentum p.d.f.	0.0013	0.0043	0.0054	0.0103
Combinatorial back. momentum p.d.f	0.0004	0.0072	0.0257	0.0065
Physics back. momentum p.d.f	0.0008	0.0002	0.0003	0.0004
Signals mass p.d.f.	0.0002	0.0066	0.0018	0.0006
Combinatorial back. mass p.d.f.	<0.0001	0.0001	<0.0001	<0.0001
Physics back. mass p.d.f	0.0001	0.0006	0.0005	0.0001
Particle Identification model	0.0023	0.0066	0.0040	0.0046
Charge asymmetry	0.0014	0.0013	0.0094	0.0096
Triggers relative efficiency	0.0003	0.0083	0.0004	0.0034
Nominal b-hadrons masses	0.0001	0.0049	0.0007	0.0008
$p_T(\Lambda_b^0)$ **spectrum**	0.0001	0.0010	0.0052	0.0021
Λ_b^0 **polarization**	<0.0001	0.0027	0.0089	0.0364
TOTAL	**0.003**	**0.02**	**0.03**	**0.04**

The Mild 2008 Excitement



$\Delta\Gamma_s$: Systematics

Source of systematic effect	$c\tau(B_s^0)$ [μ m]	$\Delta\Gamma$ [ps $^{-1}$]	$\lvert A_\parallel(0)\rvert^2$	$\lvert A_0(0)\rvert^2$	$\delta_\perp$
Signal Angular Efficiency	0.29	0.0014	0.0134	0.0162	0.076
Mass Signal Model	0.17	0.0007	0.0006	0.0020	0.018
Mass Bkg Model	0.14	0.0006	0.0003	0.0002	0.034
ct Resolution	0.52	0.0010	0.0004	0.0002	0.066
ct Bkg	1.31	0.0057	0.0006	0.0012	0.064
Angular Bkg	0.46	0.0037	0.0011	0.0022	0.009
Sigma mass	0.85	0.0006	0.0003	0.0002	0.036
Sigma ct	0.63	0.0006	0.0003	0.0002	0.038
$B_d \to J/\psi K^*$ cross-feed	0.18	0.0018	0.0002	0.0015	0.034
SVX alignment	2.0	0.0004	0.0002	0.0001	0.034
Pull bias	0.2	0.0012	0.0021	0.0008	0.02
TOT	2.7	0.007	0.014	0.017	0.15